ARTICLE IN PRESS

Water Resources and Economics (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Water Resources and Economics

journal homepage: www.elsevier.com/locate/wre

Modeling the effects of alternative mitigation measures on Atlantic salmon production in a regulated river

Ana Adeva Bustos[a,*], Richard David Hedger[b], Hans-Petter Fjeldstad[c], Knut Alfredsen[a], Håkon Sundt[c], David Nicholas Barton[d]

[a] Department of Civil and Environmental Engineering, NTNU, S. P. Andersens 5, Trondheim, Norway
[b] Norwegian Institute for Nature Research (NINA), Høgskoleringen 9, Trondheim 7043, Norway
[c] SINTEF Energy Research, Sem Sælandsvei 11, Trondheim 7048, Norway
[d] Norwegian Institute for Nature Research (NINA), Gaustadalléen 21, Oslo 0349, Norway

ARTICLE INFO

Keywords:
Energy production
Atlantic salmon production
Mitigation measures
Cost-effectiveness comparison
Fish benefit
Trade-offs analysis

ABSTRACT

As part of the investigation of a new and optimized environmental flow regime in a regulated river (Mandalselva, Norway), a modeling study was conducted on the trade-offs between the production of Atlantic salmon (Salmo salar) smolts and the production of hydropower. Impacts of alternative flow regimes on smolt production were examined under different physical mitigation scenarios using the minimum flow regime recently proposed by the Norwegian Water Resources and Energy Directorate (NVE) as a baseline. Different combinations of hydropower operational strategies and/or physical mitigation measures were examined together with changes in the minimum discharge using a series of linked simulation models with the objective of finding combinations that both increased smolt production and maintained power production. This methodology provided a toolbox for predicting both the potential tradeoffs between smolt production and power production and therefore the evaluation of the most cost-effective environmental flow regime. The main finding was that it was possible to achieve a similar smolt production with a lower hydropower plant flow release (with consequent lower power loss) than the flow regime proposed by the NVE. Introducing habitat modification measures further reduced the need for release of water in relation to the proposed minimum flow, while increasing the smolt production. In an economic cost-benefit analysis perspective, benefits per smolt from recreational fishing were small compared to hydropower costs per smolt, with hydropower losses determining optimal flow. This study concludes that the use of a modeling-based methodology to define a targeted environmental flow can be used to successfully balance the sometimes conflicting requirements of effective management of salmon populations while maintaining hydropower production.

1. Introduction

Norwegian hydropower development began more than a century ago [1]. Today, hydropower produces 97% of the country's electricity [2], and Norway is the largest hydropower producer in Europe. Approximately 70% of Norway's large rivers have been developed for hydropower, which includes ~30% of Norway's rivers which support Atlantic salmon (*Salmo salar*) populations. These rivers account for more than 40% of Norway's salmon fishery yields. There are altogether 452 Norwegian rivers, which have or have

* Corresponding author.
E-mail address: ana.adeva.bustos@ntnu.no (A. Adeva Bustos).

http://dx.doi.org/10.1016/j.wre.2017.02.003
Received 29 May 2015; Received in revised form 20 January 2017; Accepted 5 February 2017
2212-4284/ © 2017 Elsevier B.V. All rights reserved.

Please cite this article as: Adeva Bustos, A., Water Resources and Economics (2017), http://dx.doi.org/10.1016/j.wre.2017.02.003

had self-reproducing salmon populations, making Norway a core area for conservation of the world's remaining salmon. However, out of 45 extirpated Norwegian salmon populations, 19 have been extirpated as a consequence of hydropower development [3]. Given this situation, Norway has a large challenge in harmonizing hydropower generation with salmon production.

The implementation of minimum flow regimes, which specify the minimum required discharge within a regulated river, is one of the available management methods used in salmon conservation. Although minimum flow regimes have been used in regulated Norwegian rivers since the 1970's, they often lack an ecological basis and are often arbitrarily defined as being a percentage of historical flow [4]. Most minimum flow regimes differ from the definition of environmental flows found in the Brisbane Declaration [5]: "[Environmental flow] describes the quantity, quality and timing of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems". Presently, the concept for assessing minimum flow regimes is gradually shifting from rigid minimum flows to ecologically designed flow regimes in order to sustain certain ecological requirements [6,7]. This has also been driven in Norway by the implementation of the EU Water Framework Directive [8] (WFD) within the EEA-agreement. In order to reach Good Ecological Potential, which is the main requirement of the WFD in heavily modified water bodies, revision of some hydropower licences is required. For example, around 50 regulated watercourses have a high priority and 53 a low priority for hydropower license revision in the near future within Norway [9]. Therefore, it will be necessary to implement environmental flow regimes in many water courses. However, there is still no unified method to find an optimal minimum flow within such regimes.

Due to the wide ranging challenge of establishing environmental flows in hydropower operation, research has only just begun to address the difficulties of directly linking hydropower economics to operational adjustments conditioned by environmental requirements [10–13]. Jager et al. [14] found that decision analysis for the optimization of hydropower while sustaining the fish population either just prioritizes hydropower with simplified fish habitat objectives, or focuses on the relationship between reservoir release and fish, while ignoring hydropower objectives. The literature highlights the importance of calculating the hydropower revenue and the aggregate benefits to society from river ecosystems in order to find the optimal flow release [15]. Klauer et al. [16] stated that a cost-effectiveness analysis can be interpreted within the WFD as "reaching a good water status with least cost", understanding cost-effectiveness analysis as the comparison of two or more alternatives by their costs (monetary units) and effects (non-monetary units). In order to attempt to include these non-monetary values into the cost-benefit analyses, some studies use an indicator of the ecological status. This indicator can be, for example, fish production and recreational fishing [17].

In this paper, we develop a new methodology that uses a sequence of models (hydrological, hydraulic, and ecological) to investigate different scenarios for hydropower operation for optimizing the balance between energy production and salmon smolt production. The methodology was tested in the Mandalselva River (Norway), where a new minimum flow regime has been proposed by the Norwegian Water Resources and Energy Directorate (NVE). Because the proposed new minimum flow regime is not based on the natural pre-regulation status in the river (which is not well known), this proposed regime has not been validated, and may have limited potential for finding a successful solution for both ensuring energy production and sustaining the fish population. In order to analyse the river in the context of integrated watershed management and include the potential cost-effectiveness of mitigation measures to offset impacts across projects, we conduct a cost-effectiveness trade-off analysis of the application of scenario alternatives at two contrasting hydropower plants. We investigate the scenarios that support a flow that generates energy in a profitable way, while also maintaining or increasing the level of salmon production. We also investigate the potential for habitat remediation to act as an ameliorating factor for flow regimes that would maintain or increase salmon populations.

2. Materials and method

2.1. Study reach

The Mandalselva River, located in southern Norway (58°N, 7°E), is 115 km long with a catchment area of 1800 km^2 and a mean annual discharge of 88 m^3 s^{-1} (Fig. 1). The river is regulated by 6 hydropower plants and 9 reservoirs. Nearly 90% of the storage capacity is found in the Nåvann and Juvatnet reservoirs in the surrounding mountains. Atlantic salmon can migrate 47 km upstream from the sea to a final migration barrier at the Kavfossen waterfall. The two lowest hydropower plants, Bjelland and Laudal, constructed in a period when Atlantic salmon were absent from the river due to acidification of the water [18], are located within the part of the river where an introduced salmon population now resides. In order to mitigate the aesthetic effects of the low minimum flow and maintain a continuous water level in the bypasses of the hydropower plants, weirs have been constructed: two small weirs at Bjelland bypass, and 8 stone weirs and one low concrete weir at Laudal bypass.

Bjelland power plant has two Francis turbines in operation, a head of 87.5 m, an installed capacity of 53 MW and an average annual production of 312 GW h. Laudal power plant has two Francis turbines, a head of 36 m, an installed capacity of 26 MW and an average annual production of 146 GW h. In 1997, after twenty years without a salmon stock, a liming program and re-stocking strategy was initiated. This resulted in a rapid increase in the salmon population abundance. Therefore, the procedure to revise the license was started by NVE in 2002. By 2015, the Laudal hydropower plant was in the second year of a five-year trial period used to test the regulation flow specified by NVE, while in Bjelland no change in the voluntary regime has been specified by NVE.

2.2. Defining and running the discharge scenarios

The methodology developed in this study was an integrated system that combined hydrological, hydraulic and ecological modeling (Fig. 2), building upon existing and well-tested modeling tools, and linking to tools for statistical analysis and visualization

Download English Version:

https://daneshyari.com/en/article/5104959

Download Persian Version:

https://daneshyari.com/article/5104959

Daneshyari.com